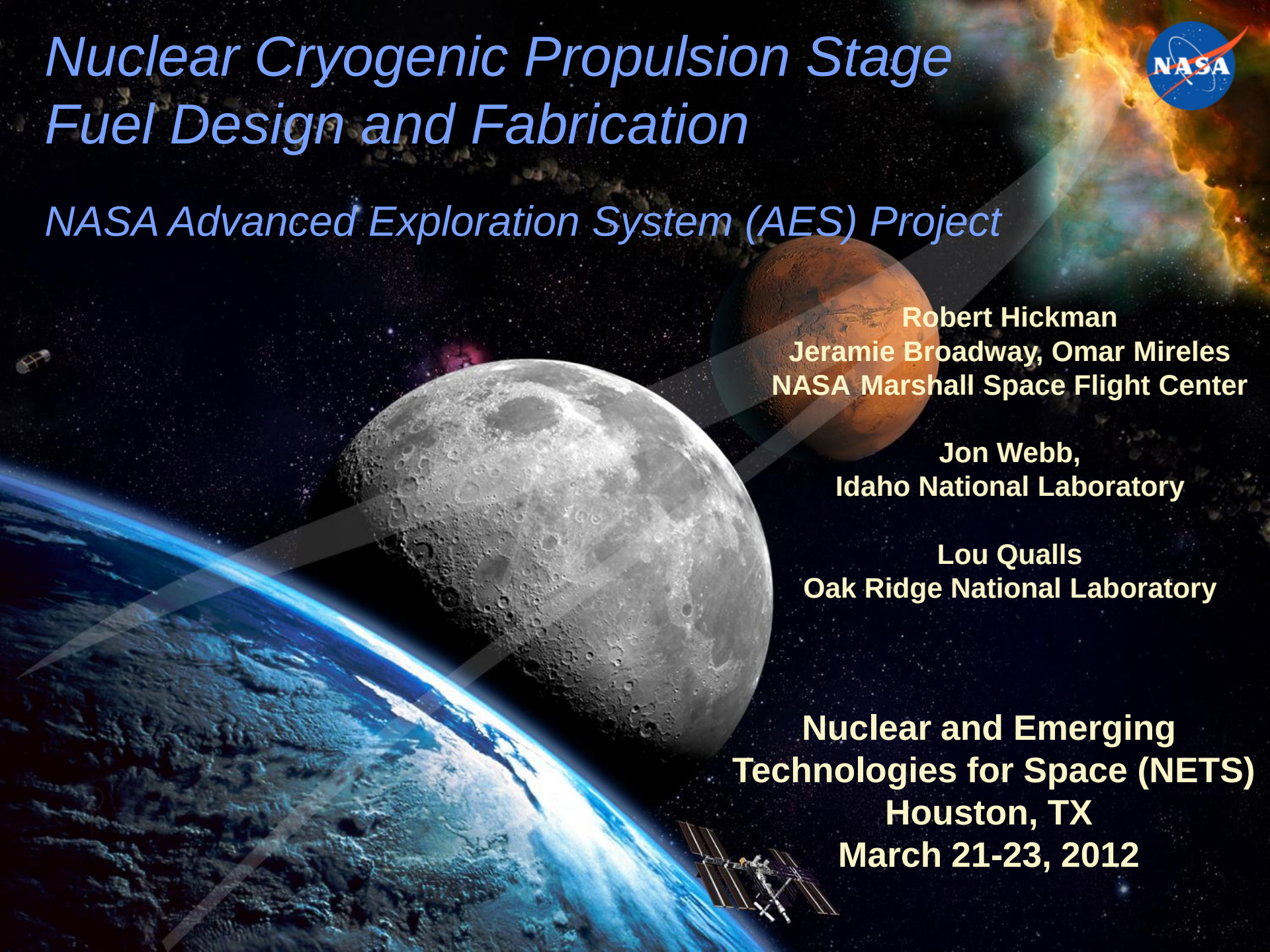
Nuclear Cryogenic Propulsion Stage Fuel Design and Fabrication

NASA Advanced Exploration System (AES) Project



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Outline

- NCPS Background
- AES NCPS Development Approach
- AES Task 4 Needs Goals and Objectives
- Fuel Down Select Criteria and Needs
- CERMET Needs
- Graphite Composite Needs
- AES Hot Hydrogen Testing
- AES Fuel Development Schedule

Advanced Exploration Systems (AES) Projects

- Development of exploration systems to reduce risk, lower cost, and validate concepts for future human missions
- Projects based on proven technologies that have a high potential for near term demonstration
- Prototype system development and test cycles rapidly converge on design requirements for flight systems
- Milestone-driven program for major hardware fabrication, system integration, and test events
- AES projects are high risk. Failures are expected, but learning from failures informs the next design and test cycle

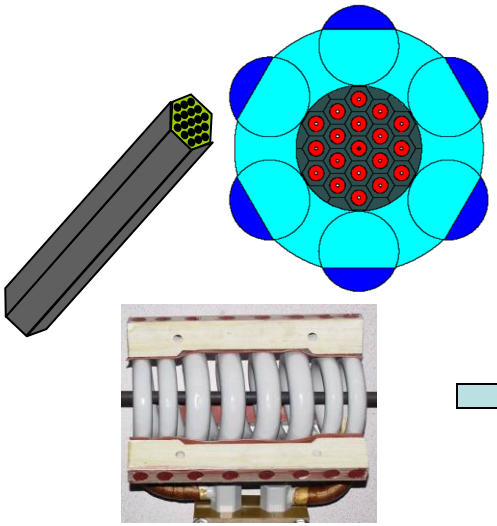
"AES is the future of NASA's human spaceflight program. Whatever we do next will begin in AES, conceived in our minds, and built with our hands"

Nuclear Cryogenic Propulsion Stage (NCPS)

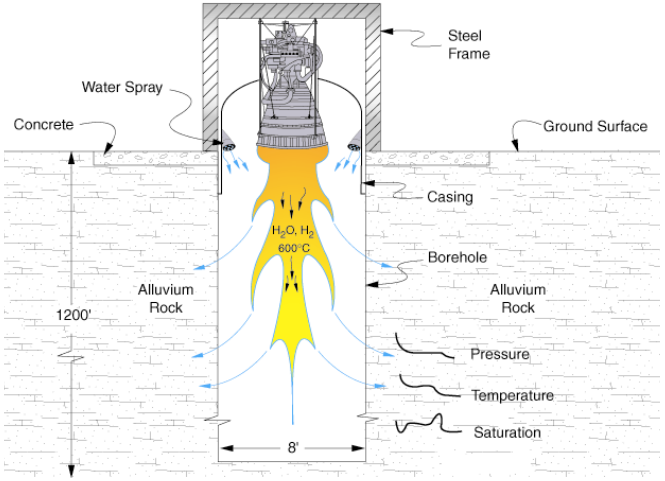
- NCPS is a game changing technology for space exploration
  - >900 sec ISP
- Goal of assessing the affordability and viability of an NCPS
- Overall tasks
  - Pre-conceptual design of the NCPS and architecture integration
  - NCPS Fuel Design and Testing
  - Nuclear Thermal Rocket Element Environmental Simulator (NTREES)
  - Affordable NCPS Development and Qualification Strategy
  - Second Generation NCPS Concepts
- Critical need for fuels development
  - Lack of qualified fuel material is a key risk
  - Development of stable fuel form is a critical path, long lead activity
- Fuel task objectives are to demonstrate capabilities and critical technologies using full scale element fabrication and testing
  - Enable future fuel optimization
  - Buy down risk for future fuel development and ground test demonstration

AES NCPS Development Approach

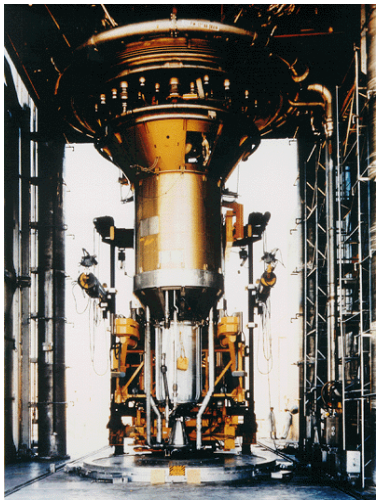
- Establish baseline exploration mission
  - Optimize development path (SLS to CPS to NCPS)
  - Baseline engine/reactor design
  - Baseline NCPS stage design
- Develop near term NCPS flight technology demonstration
  - Validate affordable and scalable design
  - Mature the necessary infrastructure and capabilities



Fuel Element Design, Fabrication, and Test AES FY12-14



Non-Nuclear Ground Testing AES FY15-20 *(Fuel Optimization/Qualification)*



Flight Technology Demonstration FY20-24

AES Task 4: Fuel Design and Fabrication

- NCPS Needs
  - Develop and down select robust fuel
  - Validate affordable fuel development and qualification plan
- FY12-14 Goals
  - Mature CERMET and Graphite based fuel materials
  - Develop and demonstrate critical technologies and capabilities
- FY12-14 Objectives
  - Develop W-UO2 CERMET fuels and fabrication capability
  - Recapture graphite composite fuels and fabrication capability
  - Characterize fuel microstructure, material properties, and performance in hot hydrogen environment
  - Perform full scale element testing of CERMET and graphite fuels
- **Highly integrated NASA/DOE fuels development team**
- **Enhance and utilize existing infrastructure and capabilities**

Fuel Down Select Criteria

- Selection criteria is not clear (finalize in 2012)
- Need informed decisional analysis/trade study
  - Tasks should be aligned with needs
- Fuel performance/producibility metrics
  - Fabricability and quality assurance
  - Time and temperature capability
  - Cycling capability
  - Fission product retention
  - Uranium density/system critical mass
- Performance and mission goals
  - ISP, thrust to weight
  - Reactor/stage requirements
  - Mission flexibility (bimodal)
- Near term demonstration
  - Cost/schedule
  - Current fuel TRL

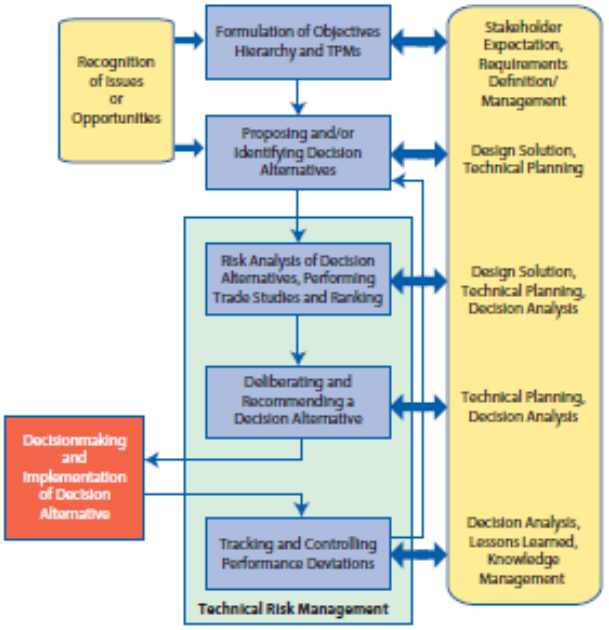


Figure 6.8-9 Risk-informed Decision Analysis Process

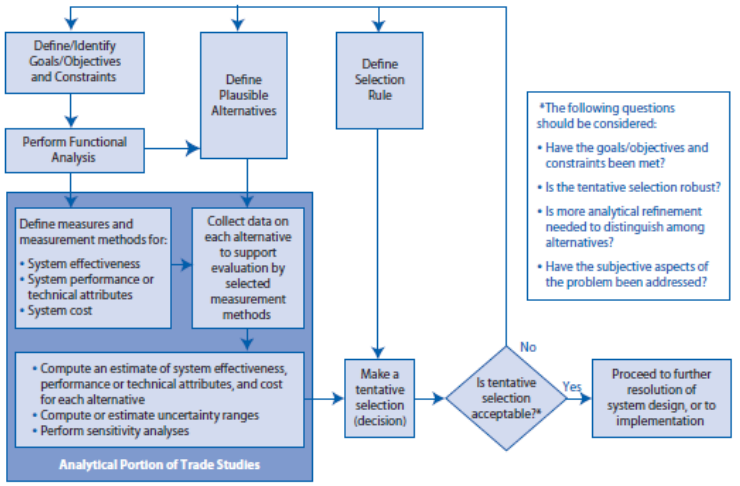


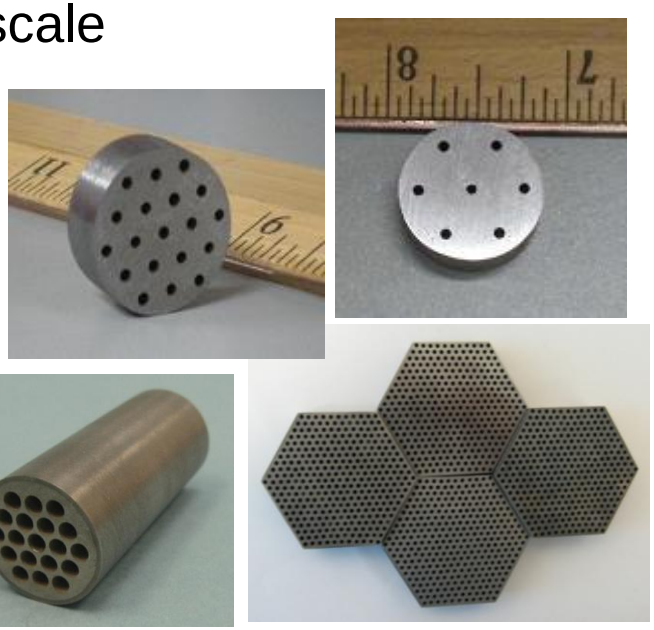
Figure 6.8-5 Trade study process

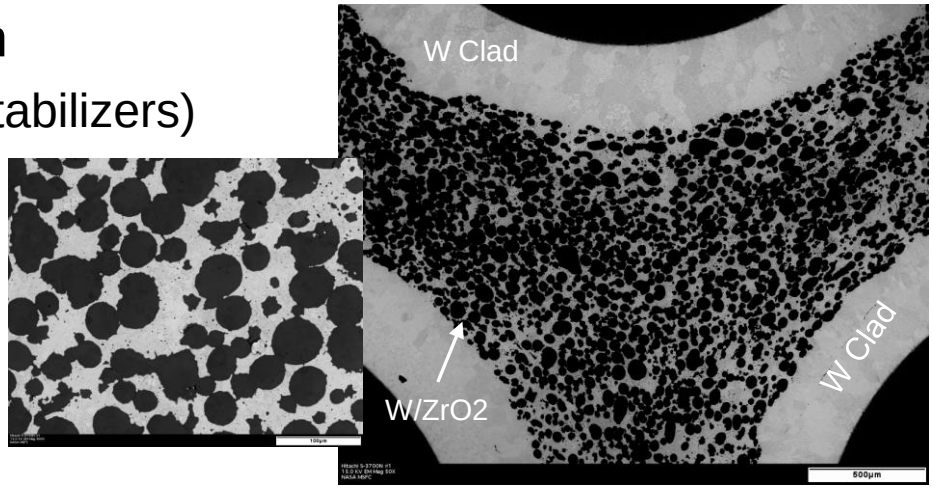
Fuel Down Select Data Needs

- Fuel sample and element fabrication capability
  - Recapture technologies and validate full scale designs
- Non-nuclear testing
  - Material properties
  - H2 compatibility/performance
  - Performance/life analysis
- Nuclear/Irradiation data
  - Need to evaluate current materials in a representative environment
  - Determine the most affordable way to match prototypic conditions (power density, temperature, flux, etc.)
  - New data may not be required for a fuel down select
- Design and Mission trades
  - Finalize designs
  - Determine key metrics and requirements
- Cost/schedule
  - Capability investment, optimization, ground test, and flight demo

W-UO2 CERMET Needs

- CERMETS demonstrated but not proven to full scale
- Demonstrate critical materials and processes
  - Develop spherical UO2 feedstock powders
  - Develop CVD W coated UO2 particles
  - Develop consolidation processes
    - Hot Isostatic Press (HIP)
    - Pulsed Electric Current (PEC)
- Establish baseline material properties
  - Tensile, thermal, and fatigue/fracture
- Assess performance in hot hydrogen
  - Composition (particle loading, size, stabilizers)
  - Form (claddings, geometry, etc)
- Irradiation data
  - Define needs for down select
  - Need to understand cost vs risk

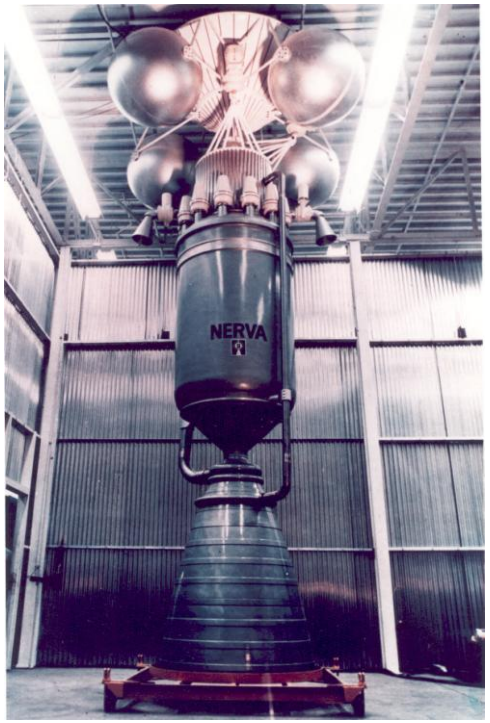


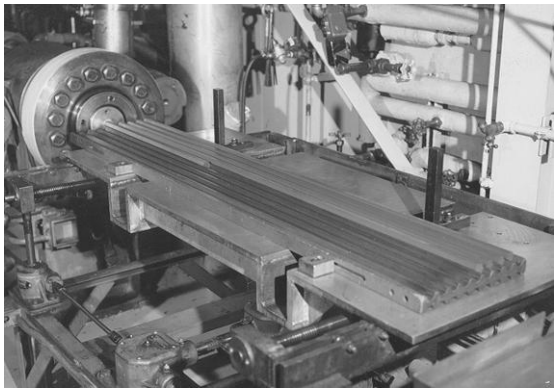


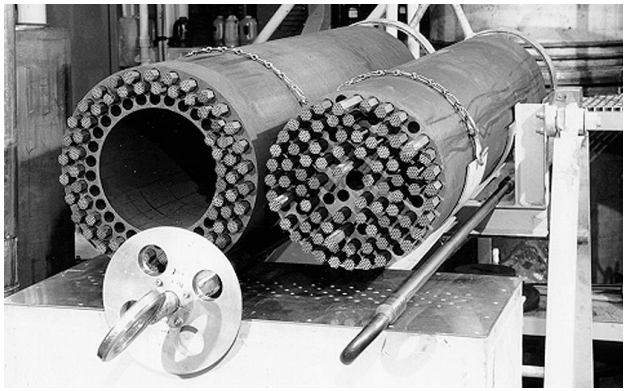
Recent Fabrication of CERMETS by HIP and PEC

Graphite Composite Needs

- Flight engines demonstrated on Rover/NERVA
  - Some materials used are obsolete
- Need to establish fabrication capabilities
  - Extrusions and coatings
- Demonstrate recapture of Rover/NERVA baseline
  - Microstructure and properties
  - Validate hot hydrogen performance for current designs
  - Enables future optimization to improve fuel performance
- Irradiation data
  - Large amount of data from Rover/NERVA
  - Need to validate current materials

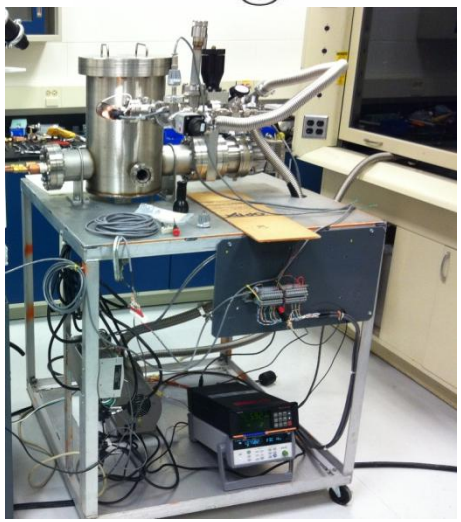






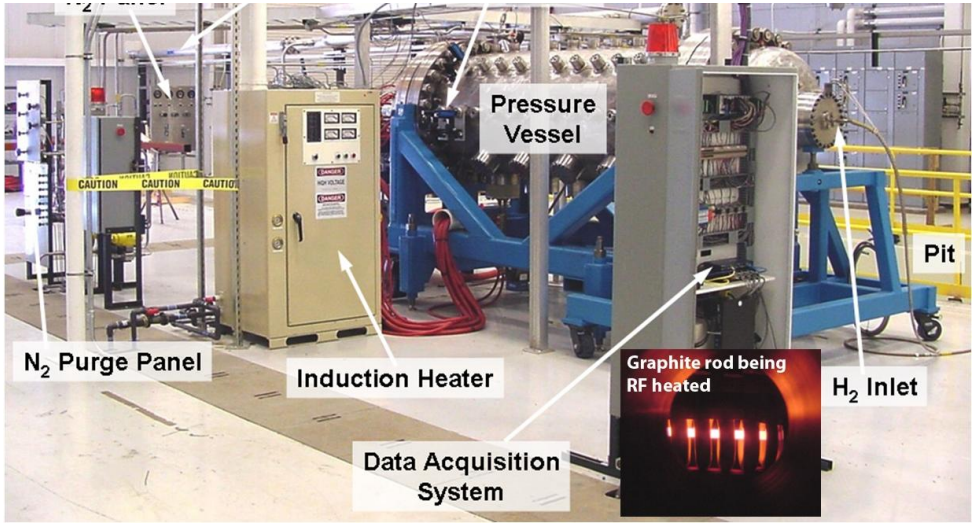
Subscale Hot Hydrogen Testing

- Critical need for screening of fuel materials in realistic environment
- Fuel stability largely driven by H2 compatibility, thermal dynamics
- Need flexible laboratory scale test system
  - Materials and process screening
- Compact Fuel Element Environment Test (CFEET)
  - Rapid testing of subscale samples (0.5” OD x 1-6” length)
  - CERMET samples successfully heated to 2775K
  - Currently integrating flowing hydrogen
- Planned AES fuel development testing
  - CERMETS
    - Evaluate process, particles size, claddings, and stabilizers
    - Vacuum, static and flowing H2 (solid rod and 7 hole samples)
  - Graphite Composites
    - Evaluate coated graphite composite (3-6” samples)
    - Validate fuel extrusion and coating processes

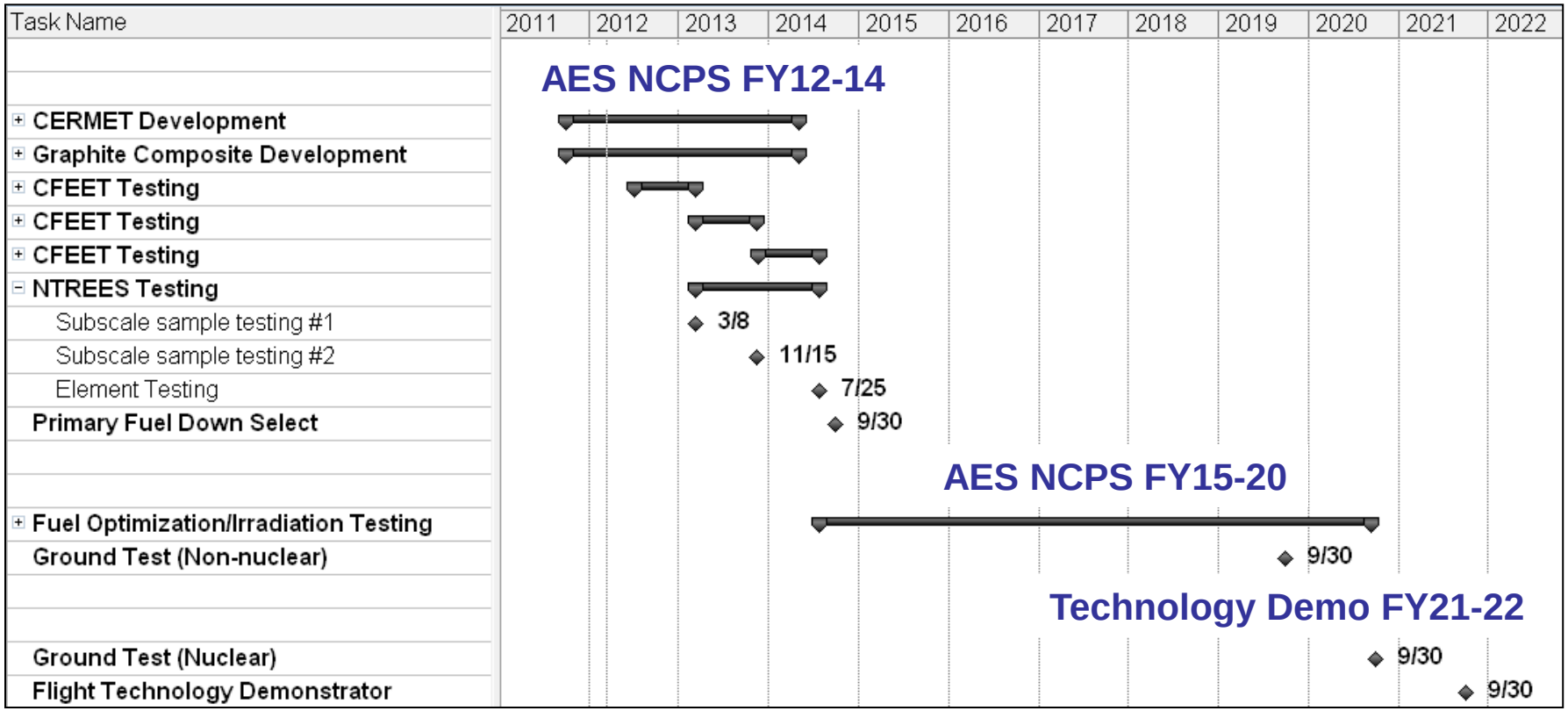


Full Scale Hot Hydrogen Testing in NTREES

- Nuclear Thermal Rocket Element Environment Simulator (NTREES)
  - Allows testing of full scale fuel elements and bundles
  - Validate fuel performance in a prototypic environment
- Designed to mimic NTP reactor conditions (minus radiation)
  - >2500 C in flowing H2 (up to 200 g/sec)
- Planned AES FY12-14 fuel development testing
  - Subscale and full scale ANL 200MW W-UO2 elements
  - Subscale Rover/NERVA graphite composite elements
  - Full scale graphite elements dependant on funding/capability costs



Fuel Development Schedule



- Fuel down selection dependant on clear criteria and decisional analysis
- Fuel optimization and irradiation testing prior to ground test
- Nuclear systems are small engine technology demonstrators

Conclusions

- AES project offers a unique opportunity to develop and demonstrate an affordable NCPS system
- Utilize a highly integrated NASA/DOE team
- Rapid development in FY12-14 using “proven” materials and process
- Full scale element fabrication and test to validate fuel materials and demonstrate capabilities
- Critical need to define fuel selection criteria to support a near term primary fuel down select
  - Required due to funding limitations
  - Tasks should be clearly aligned with down select needs
- AES FY12-14 tasks will enable follow on fuel optimization
- AES FY15-20 effort will focus on design, development, fabrication, and test of a full scale NCPS engine
- AES Project will enable an affordable follow on nuclear ground test and flight technology demonstration